Wave-Sediment Interaction in Muddy Environments: A Field Experiment

Alexandru Sheremet
Civil & Coastal Engineering
365 Weil Hall
University of Florida
Gainesville, FL 32611
phone: (352) 392-9537/1429 email: alex@coastal.ufl.edu

Mead A. Allison
University of Texas Institute for Geophysics
John A. and Katherine G. Jackson School of Geosciences
J.J. Pickle Research Campus, Bldg. 196 (ROC)
10100 Burnet Road (R2200)
Austin, TX 78758-4445
phone: 512-471-8453 email: mallison@mail.utexas.edu

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LONG-TERM GOALS

The long-term goal of the proposed work is to study and describe quantitatively the interaction between wave, currents and seabed sediments in shallow water over a bed characterized by heterogeneous, mud-dominated sediments.

This report includes two projects:

1. "Wave-Sediment Interaction in Muddy Environments: A Field Experiment", funded by Coastal Geosciences, The Coastal Geosciences project includes a field experiment on the Atchafalaya shelf, Louisiana, in Years 1 and 2 (2007-2008) and a data analysis and modeling effort in Year 3 (2009).

2. "A System for Monitoring Wave-Sediment Interaction in Muddy Environments", funded by The DURIP program.

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OBJECTIVES

The objectives of Years 1 and 2 (2007-2008) of the Coastal Geosciences (CGS) project was to conduct a pilot field experiment (2007), then a full field experiment (2008), in collaboration with other researchers funded by ONR CG program. The pilot experiment has tested the instrumentation and data analysis procedures. During the major field experiment effort in 2008 (Year 2), a total of 5 tripods were deployed at locations fronting the Atchafalaya shelf and further westward along the Chenier Coast near Freshwater Bayou. The tripods carried instrumentation for coherent measurements of waves and near-bottom sedimentary processes, including vertical structure of velocities and suspended sediment concentration, and lutocline position and motion. The dataset was supplemented with monitoring of bed character (deposition rate, porosity and stratigraphy). The project represents an effort to obtain detailed field observations (previously lacking) about the processes associated with fluid-mud layer formation and bed response to wave events, necessary for effective modeling of wave propagation over muddy shelves, as well as the role of wave activity on the processes related to the development of subaqueous clinoforms. The goal of the DURIP project was to build up the field instrumentation base to support the CGS-funded field experiment effort. This final year of the project (2009, Year 3) has been focused upon data analysis and preparation of publications.

APPROACH

Theoretical formulations of bed-induced wave dissipation are based on the assumption that wave motion reaches the bottom and interacts directly with bed sediments. Physical mechanisms for wave dissipation over muddy seabeds that have been proposed, are based on different models of sediment rheology: poro-elastic solids (Yamamoto et al., 1978; Yamamoto and Takahashi, 1985), viscous Newtonian fluids (Dalrymple and Liu, 1978), Bingham fluids (Mei and Liu, 1987), generalized Voigt solids (Jiang and Mehta, 1995; Jiang and Mehta, 1996), and non-Newtonian fluids (Chou et al., 1993; Foda et al., 1993). With the exception of liquefaction processes, these models assume a single, well-defined mud phase.

However, theoretical and laboratory evidence suggests that mud and wave processes evolve on comparable time and spatial scales, and are strongly coupled. On one hand, the efficiency and characteristics of mud-induced wave damping depends strongly on mud state. Smooth and hard consolidated muds dissipate waves at a similar, or even weaker, rate than sandy bottoms (Yamamoto and Takahashi, 1985; Lee, 1995, and others). Over non-Newtonian fluid muds (concentrations >5 kg/m^3), wave dissipation is significantly stronger (Gade, 1957; Chou et al., 1993; Foda et al., 1993). On the other hand, even under mildly energetic waves mud state can change from consolidated to fluid over the duration of one storm (Chou et al., 1993; Foda et al., 1993; also deWitt, 1995). The similar scales of evolution and the strong coupling suggest that the applicability of the above models is rather limited. While it has been hypothesized that wave-sediment coupling should be active in the field (Allison et al. 2000; Sheremet and Stone, 2003; Sheremet et al., 2005, and others), it has not been observed directly.

The basic hypothesis of the proposed work (supported by our ongoing field experiments on the Atchafalaya shelf) is that wave damping by fluid mud is only one of several dissipation mechanisms that could be active on a muddy shelf. The Louisiana coast exhibits a gradation of sediment age, type and grain size, from soft muds in the west, to more consolidated mud and fine sands to the east. The planned Dalrymple-team MURI field experiment site covers only a small fraction of this diversity, both conceptually and geographically. We propose to enhance the planned MURI field experiment by:

1. increasing the resolution of the Dalrymple-team observation array in intermediate and shallow water,

2. expanding its physics and geographic coverage to the east (Atchafalaya and Terrebonne shelf) to examine wave dissipation in areas with different sedimentary and morphologic characteristics.

RESULTS

The primary objective of the experiment of 2008 was to instrument two areas on the (extremely) wide Atchafalaya shelf to monitor cross- and along-shore wave-current-sediment interaction of the subaqueous Atchafalaya clinoform (T1 to T4, Figure 1), and in addition to support the experiment conducted by the MURI field team to the West of Freshwater Bayou (T5). The instruments were deployed for approximately two months and recorded continuously over two-week periods, with short instrument turnaround for offloading data, cleaning sensors and replacing batteries. The Freshwater Bayou platform (T5) was meant to support the data collection effort of the Elgar/Raubenheimer group (hydrodynamics and waves) with information about near-bed current-sediment dynamics. The instruments on T5 were configured to sample continuously for 4 weeks, coinciding with the activity of the Elgar/Raubenheimer cross-shore array.

All five platforms were equipped with instruments capable of high-resolution measurements of full water column hydrodynamics and near-bed sediment dynamics (Figure 2). Directional wave and current dynamics are monitored throughout the water column using an upward looking ADCP (at about 0.5-m vertical resolution), a downward looking PC-ADP which monitor near-bed flow (approximately 4-cm vertical resolution). A PUV gauge (co-located ADV and pressure sensor) are used for high resolution wave measurements. During our previous experiments we have developed a procedure to keep PC-ADP and the PUV recording continuously at 2 Hz for durations of up to two weeks. Sediment dynamics (suspended and in-bed) are monitored with ABS (sediment layer dynamics), OBS-3 (relatively dilute suspended sediment), OBS-5 (high suspended sediment concentration), and LISST aggregate and discrete particle grain-size analyzer. Additional instrumentation, e.g., vertical arrays of ADVs (Sontek Hydra) was deployed during some of the 2-week experiment periods.

Figures 3-4 show observations deep (7m; Fig. 3) and shallow water response during one of the largest frontal storm events observed in 2008 (storm from 6-9 March). Data presentation includes results of current (ADCP), wave (pressure sensor on the PC-ADP) and sea-floor evolution (PC-ADP and OBS) at tripods T1 and T3 during the frontal storm. Tripod T1 (Figure 3) is located on the foreset of the clinoform (in about 7 m of water). Tripod T3 is near the 4-m isobath, on the clinoform topset. Swell evolution shows an increase in wave dissipation during the storm. For example, the swell height peak on March 06 is approx. 0.85 to 1 m at T1 and T3 (Figure 3a and 4a), however, on March 7th the swell shows a decay from approx. 0.7 m at T1 to 0.45 m at T3. The event is associated with fairly energetic southward winds and currents which seem to be due to a superposition of low tide and the flushing of the coastal setup post-frontal storm passage. The sea-floor response can be inferred from the PC-ADP acoustic backscatter (Figures 3c-4c), based on the location of maximum intensity. While no significant changes are observed at T1 (7-m isobath), at T3 the position shows local variations (erosion/liquefaction and settling) of the order of 10-15 cm, with an overall drift (platform settling) of the order of centimeters. These results are consistent with previous observations (Jaramillo et al 2008; Sheremet et al. 2008) which suggest a significant change of wave dissipation regime during storms.

These preliminary observations also support the hypothesis that sediment resuspension/settling (and associated fluid mud formation) by frontal storms on Atchafalaya subaqueous clinoform are transient, with a life span of the same time scale as the generating storms. The differences in sea-floor response at the two stations also support the hypothesis that downslope fluid mud transport is initiated on the clinoform topset by strong wave-current stress that may involve liquefaction of the bed (suggested by the settling of the tripod). We are in the process of analyzing the data collected in Feb-April 2008 (over 100 GB of data in total) and integrating it with observations in 2006-2007.

IMPACT/APPLICATIONS

Much of the present and near-future Navy capability on predicting regional and nearshore processes assumes a sandy (non-cohesive) sedimentary environment. The present research enhances this capability by providing field data essential for model validations and by identifying processes and developing mechanisms which allow expansion into areas with significantly different characteristics.

RELATED PROJECTS

The project is coordinated in collaboration with other MURI related projects. The closest collaboration is planned with the Elgar/Raubenheimer experiment. Also related are the Trowbridge/Traykovski and Kineke/Bentley, and Herbers/O'Reilly experiments. We have a strong logistical and scientific collaboration with NRL researchers (Holland/Reed/Furokawa) working in the area examining seabed geotechnical properties.

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PUBLICATIONS

To date the following presentations and publications have been prepared and are listed below. Three other peer-reviewed papers will be submitted in the coming months.

Papers

Jaramillo, S., A. Sheremet, M. Allison, A, Reed, and K.T. Holland, “Wave-mud interactions over the muddy Atchafalaya subaqueous clinoform, Louisiana, USA: Wave-driven sediment transport,” Journal of Geophysical Research - Oceans, 114, C04002, doi:10.1029/2008JC004821, 2009.

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McAnally, W., C. Friedrichs, D. Hamilton, E. Hayter, H. Rodriguez, A. Sheremet, P.□Shrestha, and A. Teeter, “Management of fluid mud in estuaries, bays, and lakes. PART I: Present state of understanding and modeling,” Journal of Hydraulic Research, 133 (1), 2007, pp. 9-23.

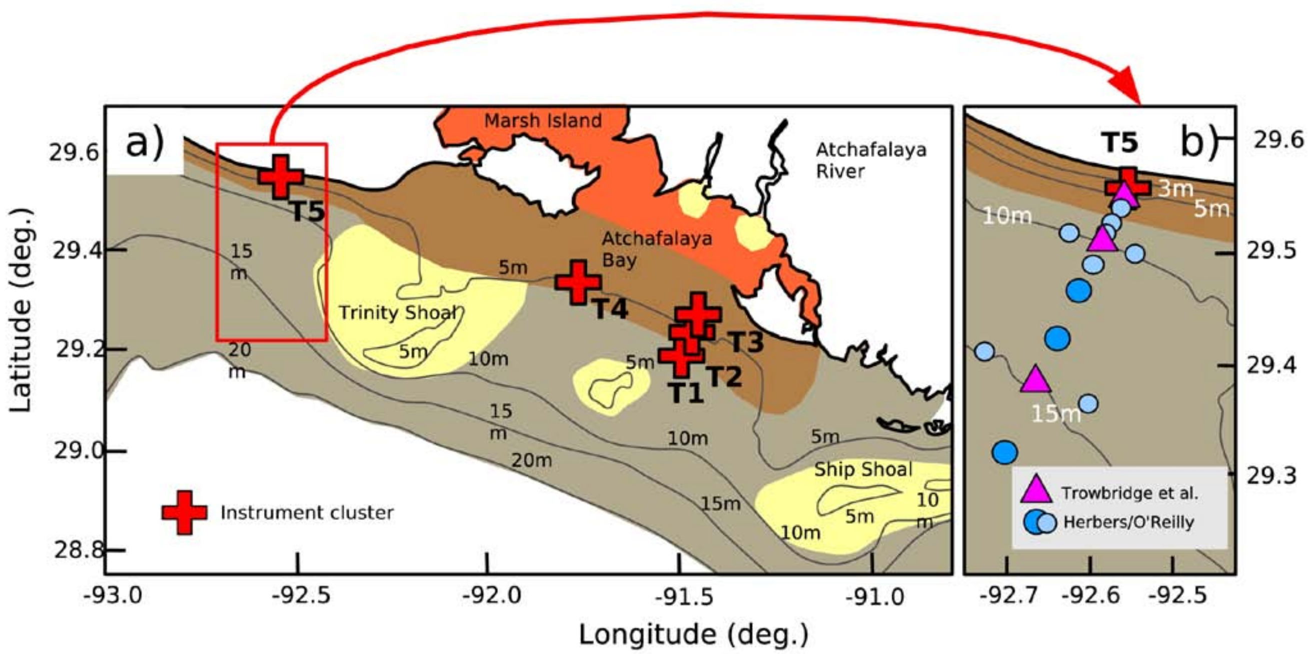

Figure 1: a) Plan view of the Atchafalaya shelf with the location of 2008 deployment locations. Three tripods were deployed approximately 4-km's apart in a cross-shore configuration of the topset (T2 and T3) and foreset (T1) of the subaqueous Atchafalaya clinoform. Alongshore wave-field variability and sediment transport was monitored using a fourth tripod (T4) deployed approximately 30 km to the West. b) Magnified area of the MURI experiment with the locations of the three MURI platforms (magenta triangles) and Herbers/O'Reilly PUV tripods (light blue circles) and buoys (dark blue circles). An additional tripod was incorporated with the instrument arrays deployed by Elgar/Raubenheinmer west of Freshwater Bayou to extend in shallow water (depth less than 4 m) the arrays of Trowbridge/Traykovsky and Herbers/O'Reill (the scale of the Elgar/Raubenheinmer array is too small to be shown).

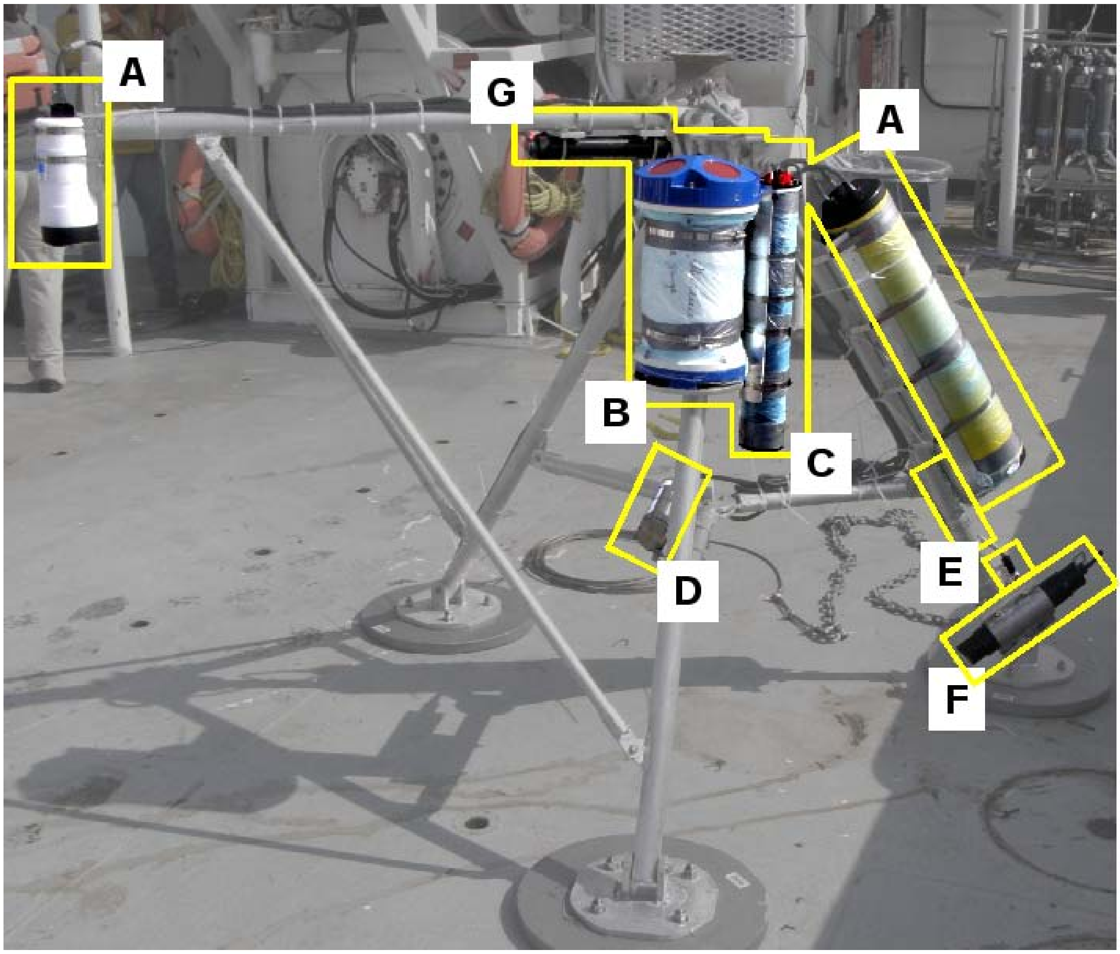

Figure 2: An instrumented platform (Tripod T1) ready for deployment. Deployed instrumentation included downward-looking PC-ADP (A), upward-looking ADCP (B), an ABS (C), a CT probe (D), turbidity sensors – one OBS-5 (F), and two OBS-3 (E, one is partially visible behind the OBS-5). An acoustic pinger (G) is used to locate the deployed tripod.

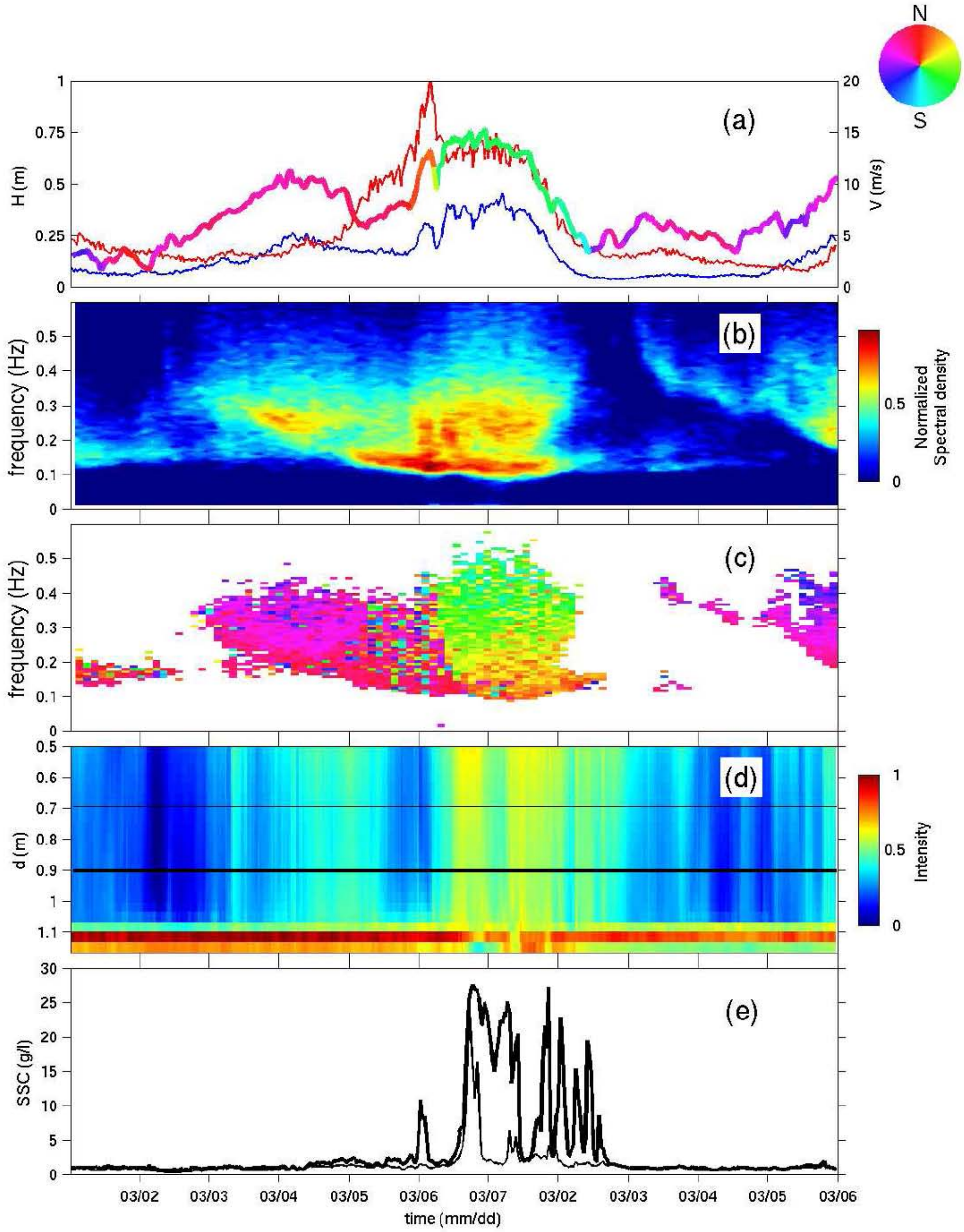

Figure 3: Observations at Platform T1 (29 deg 11.815, 91 deg 36.731 W) at a mean depth of 7m: (a) Significant wave height of sea (blue, f>0.2 Hz) and swell (red, f≤0.2 Hz) bands. Multi-color curve shows the wind speed and direction. (b) Normalized spectral density of the sea surface elevation. (c) Peak wave propagation direction for each frequency band in the power spectrum (for both winds and waves, the directions indicate where the flow is toward, i.e., N means toward North). The wave directions are shown only for frequencies with spectral density above a lower limit. (d) Normalized acoustic backscatter records of the downward-pointing PC-ADP. The two lines indicate the locations of the sediment concentration gauges. (e) Suspended sediment concentration at 18 cm above bed (thick line) and 40 cm above bed (thin line).

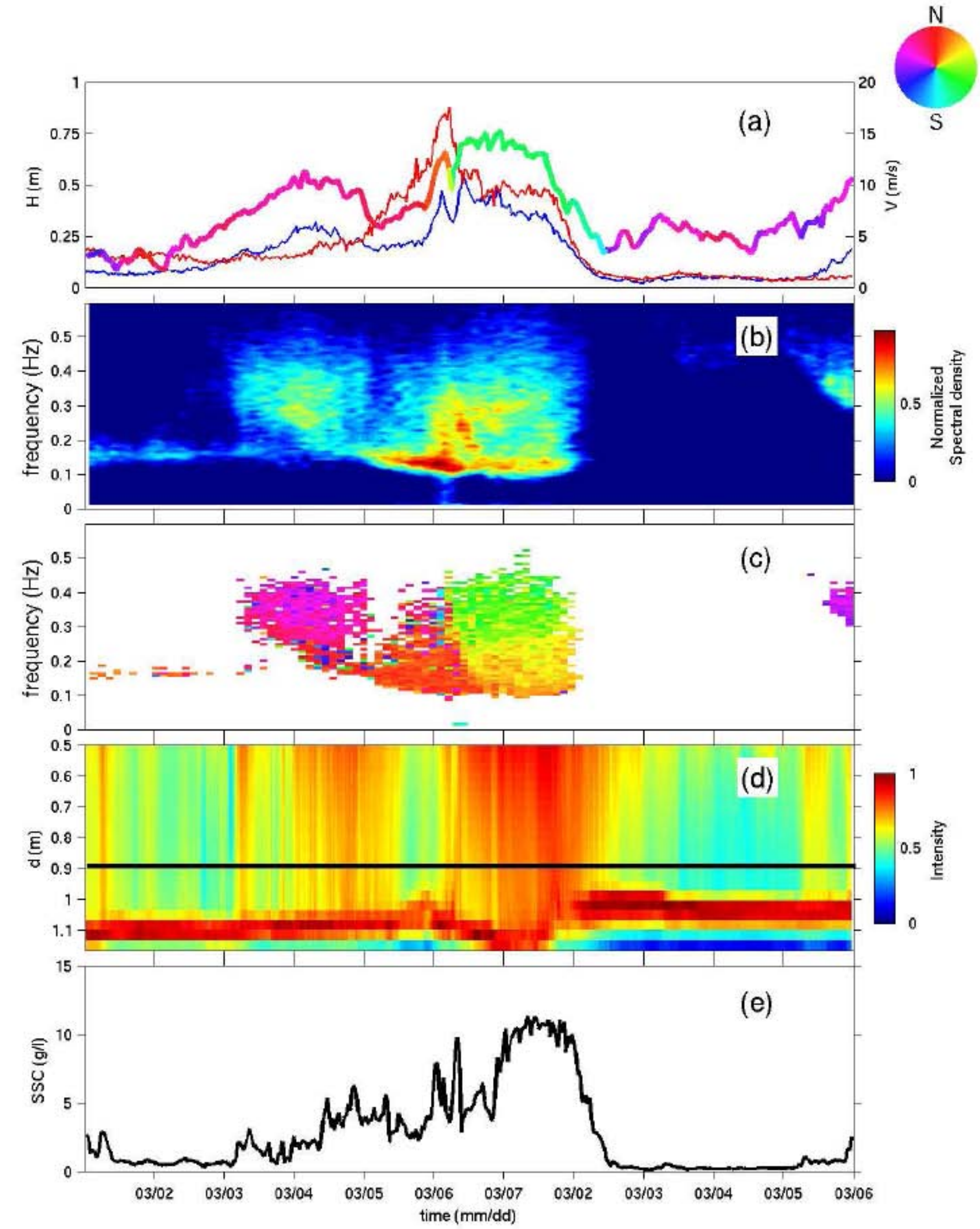

Figure 4: Observations at Platform T3 (29 deg 15.574, 91 deg 34.267W) at a mean depth of 4m: (a) Significant wave height of sea (blue, f>0.2 Hz) and swell (red, f≤0.2 Hz) bands. Multi-color curve shows the wind speed and direction. (b) Normalized spectral density of the sea surface elevation. (c) Peak wave propagation direction for each frequency band in the power spectrum (for both winds and waves, the directions indicate where the flow is toward, i.e., N means toward North). The wave directions are shown only for frequencies with spectral density above a lower limit. (d) Normalized acoustic backscatter records of the downward-pointing PC-ADP. The line indicates the location of the sediment concentration gauge. (e) Suspended sediment concentration at 18 cm above bed.

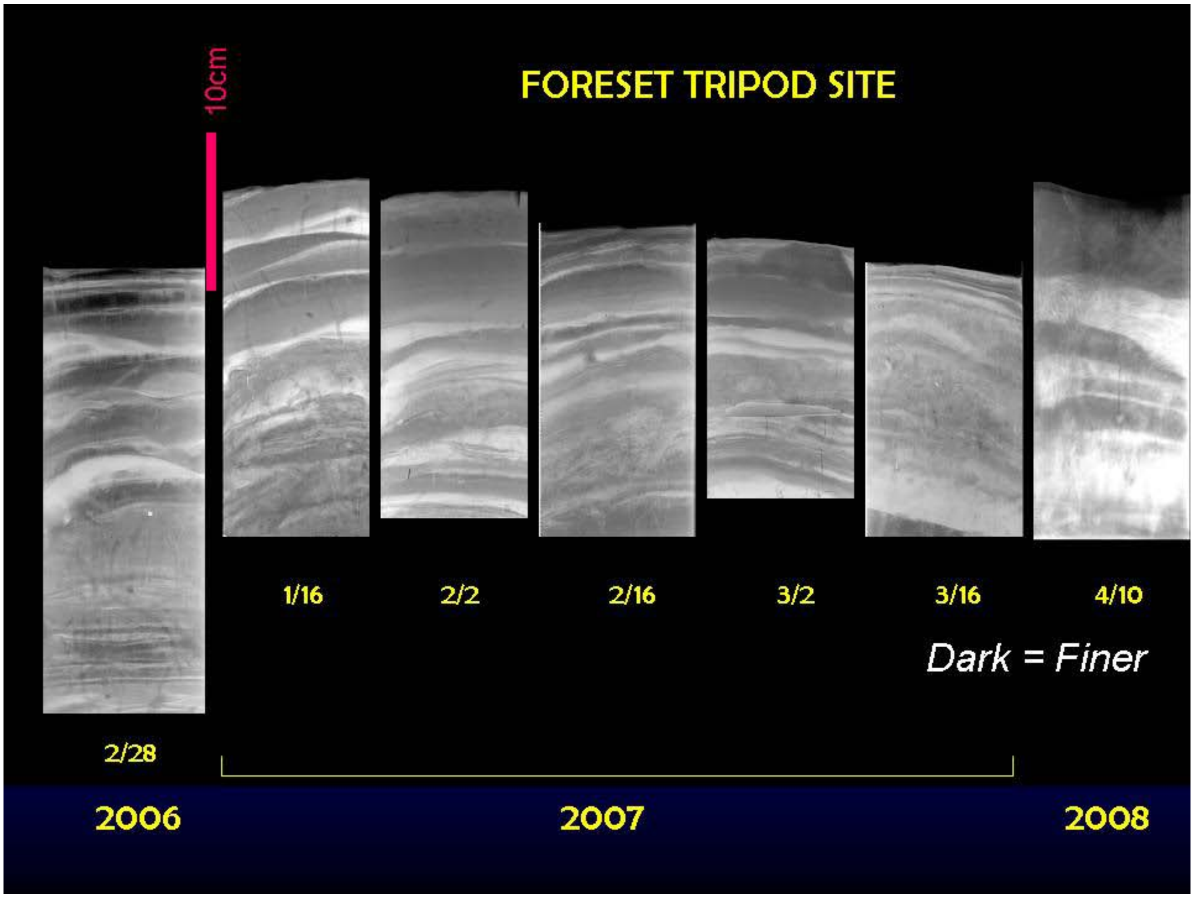

Figure 5. X-radiograph positives (dark=finer sediment) of upper seabed stratigraphic evolution at the foreset (T1) site taken from cores collected during two week turnarounds of the tripods. Only one date is shown in 2006 and 2008, while all the 2007 dates are shown. These data demonstrate the complex response of upper seabed stratigraphy to the multiple frontal storms experience yearly and are likely a combination of normal resuspension-deposition cycles (smaller events) and fluid-mud depositional events (larger events).

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Conference Presentations

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